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(54) Method of lighting discharge lamp and discharge lamp lighting apparatus.

(57) A discharge lamp (18) is connected to the output terminal of a lighting circuit (100). A starting circuit (200) is connected in parallel with the discharge lamp (18). A driver (104) and a transistor (116) in the lighting circuit (100), and a transistor (64) on the starting circuit (200) side serve to control a timing at which an output from the lighting circuit (100) is supplied to the discharge lamp (18). When a power source (12) is tuned on, a glow discharge of the discharge lamp (18) is maintained by the transistor (64) using power supplied from a pulse transformer (202) of the starting circuit (200). Subsequently, the glow discharge is shifted to an arc discharge by power supply from the lighting circuit (100) in accordance with a predetermined timing control operation by means of the driver (104) and the transistor (116), thereby lighting the discharge lamp (18).

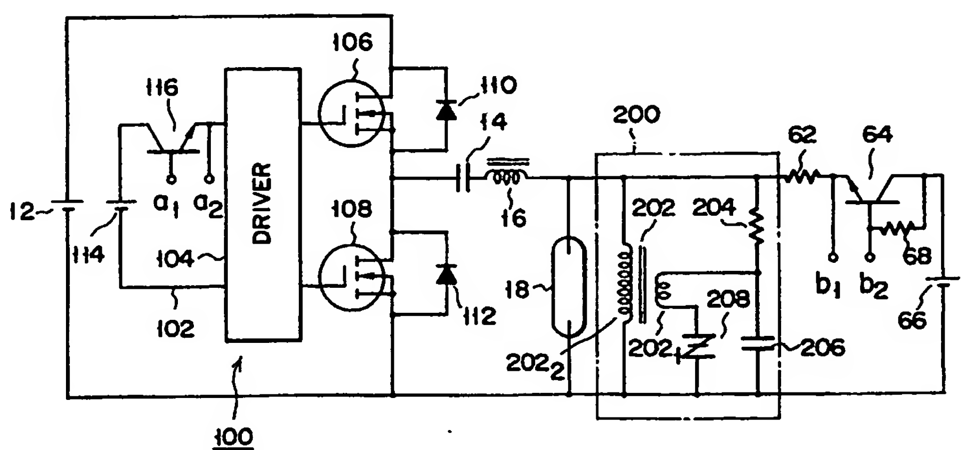

FIG. 1

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METHOD OF LIGHTING DISCHARGE LAMP AND DISCHARGE LAMP LIGHTING APPARATUS

The present invention relates to a method of lighting a discharge lamp and a lighting apparatus for the discharge lamp and, more particularly, to a method of lighting a discharge lamp and a lighting apparatus for the discharge lamp, in which a timing at which an output from a lighting circuit is supplied to the discharge lamp after the discharge of the discharge lamp is started is controlled.

As a conventional discharge lamp lighting apparatus, an apparatus disclosed in, e.g., Published Unexamined Japanese Patent Application No. 63-150892 is known. In this discharge lamp lighting apparatus, a lighting circuit is formed by connecting an inverter having four transistors as switching elements to a power source, and a discharge lamp is connected to the output terminal of the lighting circuit through a choke coil and the secondary winding of a pulse transformer. In addition the primary winding of the pulse transformer is connected to a starting circuit constituted by a thyristor, a constant-voltage conducting element, and a plurality of capacitors and resistors. A pulse voltage is to be applied from this starting circuit to the discharge lamp.

In the discharge lamp lighting apparatus having such an arrangement, when the power source is turned on, the inverter starts an oscillating operation. That is, the constant-voltage conducting element is ON/OFF-operated to ON/OFF-operate the thyristor. As a result, a high-voltage pulse is generated at the secondary winding of the pulse transformer and is applied across the discharge lamp. The discharge lamp is started by this high-voltage pulse, and is subsequently lighted by an output from the inverter. When the discharge lamp is lighted, since the voltage between the two ends of the discharge lamp drops, the operation of the starting circuit is stopped.

In the apparatus in which the secondary winding of the pulse transformer is interposed between the output terminal of the lighting circuit and the discharge lamp as described above, however, since one end of the secondary winding is directly connected to the discharge lamp, and the other end is connected to the discharge lamp through the lighting circuit, a high-voltage pulse generated at the secondary winding is reduced by the lighting circuit. For this reason, the pulse voltage of a high-voltage pulse must be set to be undesirably high.

In addition, a high-voltage pulse or a pulse current generated at the secondary winding may run around and nter the lighting circuit, and may damage switching elements such as transistors.

Moreover, when the discharge lamp is to be lighted by a high-frequ ncy wave or a lighting wave on which a high-frequency wave is superposed, since the inductance of the secondary winding is greatly increased, proper power cannot be supplied to the discharge lamp. In order to solve this problem, the inductance may be reduced. However, if the inductance is reduced, a sufficient high-voltage pulse cannot be obtained at the start of a lighting operation. Hence, the lighting operation cannot be started.

It is, therefore, an object of the present invention to provide a method of lighting a discharge lamp and a lighting apparatus for the discharge lamp, in which a pulse voltage can be applied to the discharge lamp without loss, and a breakdown of switching elements of a lighting circuit can be prevented by preventing a high-voltage pulse or a pulse current from being supplied to the lighting circuit at the start of a lighting operation.

According to a first aspect of the present invention, there is provided a method of lighting a discharge lamp comprising the steps of supplying a starting high voltage, required for starting an initial discharge of the discharge lamp; maintaining the initial discharge by supplying power lower than a predetermined power required for main lighting; and supplying a predetermined power required for main lighting of the discharge lamp to the discharge lamp, while the initial discharge is maintained.

According to a second aspect of the invention, there is provided a discharge lamp lighting apparatus comprising a discharge lamp; a lighting circuit, having an output terminal connected to said discharge lamp, for supplying a predetermined power to the discharge lamp to effect main lighting of the discharge lamp; and a starting circuit, connected to said discharge lamp in parallel with said lighting circuit, for starting initial discharge of the discharge lamp and maintaining the initial discharge with power lower than a predetermined power supplied from the lighting circuit to the discharge lamp,
characterized by further comprising a control circuit for controlling a timing at which a predetermined power from the lighting circuit is supplied to the discharge lamp after the initial discharge is started by the starting circuit and while the initial discharge is maintained.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a circuit diagram showing an arrangement of a discharge lamp lighting apparatus according to an embodiment of the present invention;

Figs. 2A and 2B are timing charts showing an operation timing of the discharge lamp lighting apparatus in Fig. 1;

Fig. 3 is a circuit diagram showing an arrangement of a discharge lamp lighting apparatus according to the second embodiment of the present invention;

Figs. 4A and 4B are timing charts showing an operation timing of a relay of the discharge lamp lighting apparatus in Fig. 3;

Fig. 5 is a circuit diagram showing an arrangement of a discharge lamp lighting apparatus according to the third embodiment of the present invention;

Figs. 6A and 6B are timing charts showing an operation timing of the discharge lamp lighting apparatus in Fig. 5;

Fig. 7 is a circuit diagram showing an arrangement of a starting circuit, as a modification, in the discharge lamp lighting apparatuses in Figs. 1, 3, and 5;

Fig. 8 is a circuit diagram showing an arrangement of another modification of the starting circuit in the discharge lamp lighting apparatuses in Figs. 1, 3, and 5;

Fig. 9 is a circuit diagram showing an arrangement of still another modification of the starting circuit in the discharge lamp lighting apparatuses in Figs. 1, 3, and 5;

Fig. 10 is a circuit diagram showing an arrangement of a discharge lamp lighting apparatus according to the fourth embodiment of the present invention;

Figs. 11A and 11B are timing charts showing an operation timing of the discharge lamp lighting apparatus in Fig. 10;

Fig. 12 is a circuit diagram showing an arrangement of a starting circuit, as a modification, in the discharge lamp lighting apparatus in Fig. 10;

Fig. 13 is a circuit diagram showing an arrangement of another modification of the starting circuit in the discharge lamp lighting apparatus in Fig. 10;

Fig. 14 is a circuit diagram showing an arrangement of a discharge lamp lighting apparatus according to the fifth embodiment of the present invention;

Fig. 15 is a circuit diagram showing a detailed arrangement of a relay switching circuit in Fig. 14;

Figs. 16A to 16I are timing charts showing an operation timing of each component of the discharge lamp lighting apparatus in Fig. 14 in a normal lighting operation; and

Figs. 17A to 17I are timing charts showing an operation timing of each component of the discharge lamp lighting apparatus in Fig. 14 in a lighting operation including failures to cause the discharge lamp to discharge and to ke p a discharge.

Embodiments of the present invention will be described below with reference to the accompanying drawings.

As shown in Fig. 1, a discharge lamp lighting apparatus according to the present invention is designed such that an inverter 102 for supplying a high-frequency output is connected to a first DC power source 12 so as to constitute a lighting circuit 100, and a discharge lamp, e.g., a high-voltage discharge lamp 18 is connected to the output terminal of the lighting circuit 100, i.e., the output terminal of the inverter 102, through a series circuit of a capacitor 14 and a choke coil 16.

The inverter 102 includes two MOS transistors 106 and 108 having gates connected to a driver 104. Each of diodes 110 and 112 having polarities shown in Fig. 1 is connected between the source and the drain of a corresponding one of the MOS transistors 106 and 108. The drain of the transistor 108 is connected to the source of the transistor 106, and the DC power source 12 is connected between the drain of the transistor 106 and the source of the transistor 108. Note that the driver 104 serves to alternately switch the transistors 106 and 108.

In addition, the negative electrode of a DC power source 114 and the emitter of a transistor 116 having a collector connected to the positive electrode thereof are connected to the driver 104. The transistor 116 is used to control the driver 104. As will be described later, the driver 104, i.e., the inverter 102 (the lighting circuit 100), is ON/OFF-controlled by a voltage to be applied to the base of the transistor 116.

In addition to the lighting circuit 100, a starting circuit 200 is connected to the discharge lamp 18. In the starting circuit 200, a secondary winding 202_2 of a pulse transformer 202 as a high voltage generator is connected in parallel with the discharge lamp 18. The secondary winding 202_2 of the pulse transformer and a series circuit of a resistor 204 and a capacitor 206 are connected in parallel. Furthermore, a primary winding 202_1 of the pulse transformer 202 is connected in parallel with the capacitor 206 through a semiconductor switch 208.

The series circuit of the resistor 204 and the capacitor 206 of the starting circuit 200 is connected to a second DC power source 66 through a series circuit of a resistor 62 and the collector and mitter of a transistor 64. In addition, a resistor 68 is connected betw n the base and coll ctor of the transistor 64. As will be described later, a pred t r-mined voltage is applied to the base of the transistor 64.

Note that one power source may be commonly

used as the first and second power sources 12 and 66.

An a_1-a_2 voltage is applied to the base-emitter path of the transistor 116 at a timing shown in Fig. 2A. A b_1-b_2 voltage is applied to the base-emitter path of the transistor 64 at a timing shown in Fig. 2B.

An operation of the discharge lamp lighting apparatus having the above described arrangement will be described below. The b_1-b_2 voltage is applied to the base-emitter path of the transistor 64 at time t_0 shown in Figs. 2A and 2B so as to turn on the transistor 64. The starting circuit 200 is then connected to the second DC power source 66 through the resistor 62, and an operation of the circuit 200 is started. When the starting circuit 200 is operated, a pulse current periodically flows in the primary winding 202_1 of the pulse transformer 202, and a high-voltage pulse is generated at the secondary winding 202_2. This high-voltage pulse is applied across the discharge lamp 18 so that the discharge lamp 18 starts an initial glow discharge. Then, initial glow discharge is maintained by the power supplied from the starting circuit 200. The power supplied in this case is lower than a predetermined value needed for main lighting.

Subsequently, the a_1-a_2 voltage is applied to the base-emitter path of the transistor 116 of the lighting circuit 100 at time t_1 so as to turn on the transistor 116. As a result, the driver 104 is started to alternately switch the transistors 106 and 108. With this operation, a predetermined high-frequency power, which is greater than the power supplied from the starting circuit 200 to the discharge lamp 18, is supplied from the inverter 102 to the discharge lamp 18 through the capacitor 14 and the choke coil 16.

Thus, the state of the discharge lamp 18 is shifted from the initial glow discharge to a main arc discharge, and a normal lighting operation is performed. When the transistor 64 is turned off at time t_2, the operation of the starting circuit 200 is stopped.

In this manner, the starting circuit 200 is operated first to cause the initial glow discharge of the discharge lamp 18, and this glow discharge is maintained with a low power for a predetermined period of time. Subsequently, the lighting circuit is operated to shift the state of the discharge lamp 18 from the initial glow discharge to the main arc discharge. Specifically, the lighting circuit 100 is operated after the discharge lamp 18 starts discharg and the impedance lowers. Thus, high voltage is applied to the transistors 106 and 108. As a result, a large switching loss can be prevented, and a switching op ration of the transistors 106 and 108 can be performed within a safe operating region.

In particular, when th initial discharg is maintained, the impedance of the discharge lamp 18 lowers, and therefore the pulse which is generated at th secondary winding 202_2 of the pulse transformer 202 is reduced by the discharge lamp 18. For this reason, even if this high-voltage pulse runs around during an operation of, e.g., the lighting circuit 100, there is no possibility that the transistors 106 and 108 are damaged. In addition, the lighting circuit 100 is not operated before the discharge lamp 18 starts initial discharge. Thus, even if the high-voltage pulse is applied to the transistors 106 and 108, these transistors are not damaged.

Note that the secondary winding 202_2 of the pulse transformer 202 serves as a high impedance with respect to a high-frequency output from the lighting circuit 100. For this reason, there is no possibility that power loss is caused by the secondary winding 202_2, and hence a lighting operation of the discharge lamp 18 is performed by proper power.

Furthermore, in this embodiment, the operation timing of the lighting circuit 100 is controlled by the ON/OFF operation of the transistor 116. However, the same effects as described above can be obtained even if the operation timing of the lighting circuit 100 is controlled by the ON/OFF operation of the power source 12 itself.

The second embodiment of the present invention will be described below with reference to Fig. 3 and Figs. 4A and 4B. Note that the same reference numerals in the second embodiment denote the same parts as in the first embodiment, and a detailed description thereof will be omitted.

Referring to Fig. 3, a choke coil 20 having a relatively large inductance is series-connected between a choke coil 16 and a discharge lamp 18. A normally-open contact 22m of a first relay 22 is connected in parallel with the choke coil 20. The normally-open contact 22m is ON/OFF-operated by a first relay driver 24 at a timing shown in Fig. 4A.

A starting circuit 200 is connected to a second DC power source 66 through a series circuit of a normally-open contact 70m of a second relay 70 and a resistor 62. The second relay 70 is ON/OFF-operated by a second relay driver 72 at a timing shown in Fig. 4B.

Note that a lighting circuit 100_1 is obtained by omitting the timing circuits for the lighting circuit, such as the power source 114 and the control transistor 116, from the lighting circuit 100 shown in Fig. 1.

In the second embodiment, when the second relay 70 is turned on by the second relay driver 72 at time t_0, the normally-open contact 70m is clos d. The starting circuit 200 is then operated, and the discharge lamp 18 is started/lighted by a

high-voltage pulse from a secondary winging 202_2 of a pulse transformer 202. As a result, the discharge lamp 18 starts an initial glow discharge. At this time, the power supplied from the starting circuit 200 is lower that the power needed for main lighting.

The lighting circuit 100_1 is also operated at this time. However, since the two choke coils 16 and 20 are connected between the output terminal of the lighting circuit 100_1 and the discharge lamp 18, the composite impedance of the coils 16 and 20 with respect to the high-frequency output from the lighting circuit 100_1 is large. For this reason, high-frequency power supplied to the discharge lamp 18 is small. Therefore, at this time, the operation of the discharge lamp 18 is not shifted to an arc discharge.

When the first relay 22 is operated by the first relay driver 24 at time t_1, the normally-open contact 22m is closed. As a result, the choke coil 20 is short-circuited, and hence proper high-frequency power is supplied to the discharge lamp 18. The operation of the discharge lamp 18 is then shifted from an initial glow discharge to a main arc discharge, and a normal lighting operation is performed. At time t_2, the second relay is turned off to stop the starting circuit 200.

As described above, in the second embodiment, the normally-open contact 22m of the relay 22 is opened before the discharge lamp 18 starts the initial discharge. Thus, the high-voltage pulse applied to the discharge lamp 18 is not applied directly to the transistors 106 and 108 in the lighting circuit 100_1 which is being operated. The contact 22m of the relay 22 is closed after the discharge lamp 18 starts the initial discharge. Thus, in the second embodiment, like the above-described first embodiment, the switching loss of the transistor can be reduced and the destruction of the transistor can be prevented.

In this embodiment, therefore, the same effects as in the first embodiment can be obtained.

In the second embodiment, the timing circuits for the lighting circuit, such as the power source 114 and the transistors 116 shown in Fig. 1 are omitted. However, these circuits may be arranged. With these circuits, the lighting circuit in the second embodiment can be operated at the same timing as in the first embodiment.

The third embodiment of the present invention will be described below with reference to Fig. 5 and Figs. 6A and 6B. Note that the same reference numerals in the third embodiment denote the same parts as in the above-described embodiments, and a detailed description thereof will b omitted.

Referring to Fig. 5, the node of the cathode of a diode 26_1 and th anode of a diode 26_2 and the node of the cathode of.a diode 26_3 and the anode of a diode 26_4 are r spectively connected to the two ends of a choke coil 20. The diodes 26_1 to 26_4 constitute a diod bridge circuit 26. The collector and emitter of a transistor 28 are respectively connected to the node of the cathodes of the diodes 26_1 and 26_3 and the node of the anodes of the diodes 26_2 and 26_4. In addition, the base and emitter of the transistor 28 are respectively connected to the output terminals of an amplifier 30. The amplifier 30 is driven/controlled by a timer 34 connected to a third DC power source 32.

The collector and emitter of a phototransistor 74a of a photocoupler 74 are respectively connected to the base and emitter of a transistor 64. A light-emitting diode 74b of the photocoupler 74 is connected to an output terminal of an amplifier 76. The amplifier 76 is driven/controlled by a timer 80 connected to a fourth DC power source 78.

A c_1-c_2 voltage is applied from the amplifier 30 to the base-emitter path of the transistor 28 at a timing shown in Fig. 6A. A b_1-b_2 voltage is applied from the amplifier 76 to the base-emitter path of the transistor 64 through the photocoupler 74 at a timing shown in Fig. 6B.

In the third embodiment, the amplifier 76 is driven first by the timer 80 at time t_0. The transistor 64 is then turned on to drive a starting circuit 200. As a result, a high-voltage pulse is generated by a secondary winding 202_2 of a pulse transformer 202, and the discharge lamp 18 is started to establish an initial glow discharge. At this time, the power supplied from the starting circuit 200 to the discharge lamp 18 is lower than the power needed for main lighting. In addition, a lighting circuit 100_1 is operated. However, since two choke coils 16 and 20 are series-connected between the output terminal of the lighting circuit 100_1 and the discharge lamp 18 in series, the composite impedance of the coils 16 and 20 with respect to the high-frequency output from the lighting circuit 100_1 is increased. Therefore, the high-frequency power to be supplied to the discharge lamp 18 is reduced, and the operation of the discharge lamp 18 is not shifted to an arc discharge at this time.

Subsequently, the amplifier 30 is driven by the timer 34 at time t_1 to turn on the transistor 28. With this operation, the choke coil 20 is short-circuited through the diode bridge circuit 26. Proper high-frequency power is supplied from the lighting circuit 100_1 to the discharge lamp 18, and the operation of the discharge lamp 18 is shifted from the initial glow discharge to a main arc discharge so as to be normally operated.

In the third embodiment, too, after the discharge lamp 18 starts the initial discharge, the choke coil 20 is bypassed by the diode bridge circuit 26 and th lighting circuit 100_1 is connected directly to th starting circuit 200. Thus, in the third

embodiment, like the first and second embodiments, the switching loss of the transistor can be reduced and the destruction of the transist r can be prevented.

In the third embodiment, the transistor 64 is turned off at time t_2 by means of the timer 80. After the discharge lamp 18 is turned on, the starting circuit 200, the operation of which has become unnecessary, is turned off. Thus, power consumption is reduced.

In the embodiments shown in Figs. 1, 3, and 5, the starting circuit is constituted by the pulse transformer 202 having one primary winding and one secondary winding, the resistor 204, the capacitor 206, and the semiconductor switch 208. However, the present invention is not limited to this.

Fig. 7 shows a modification of the starting circuit.

Referring to Fig. 7, a starting circuit 200_1 includes a pulse transformer 210 as a high voltage generator having two primary windings 210_{11} and 210_{12} and one secondary winding 210_2. One end of one primary winding 210_{11} of the pulse transformer 210 is connected to the node of a resistor 204 and a capacitor 206 which are connected in series. The other end of one primary winding 210_{11} is connected to the anode of a unidirectional three-terminal thyristor 212. One end of the other primary winding 210_{12} of the pulse transformer 210 is connected to the node of a resistor 214 and a capacitor 216 which constitute a series circuit together with a resistor 218. The other end of the primary winding 210_{12} is connected to one end of a semiconductor switch 208.

The gate of the thyristor 212 is connected to the node of the capacitor 216 and the resistor 218. One end of each of the secondary winding 210_2 and the resistors 204 and 214 is connected to one end of a discharge lamp 18. The other end of each of the capacitor 206, the resistor 218, and the semiconductor switch 208, and the cathode of the thyristor 212 are connected to the other end of the discharge lamp 18.

A high-voltage pulse is also generated at the secondary winding 210_2 of the pulse transformer 210 by using the starting circuit 200_1 having the above-described arrangement. Therefore, the starting circuit 200_1 provides the same function as that of the starting circuits 200 shown in Figs. 1, 3, and 5.

Fig. 8 shows another modification of the starting circuit.

Referring to Fig. 8, a lighting circuit 100_2 is designed such that an inverter 120 having four transistors 36, 38, 40, and 42 as switching elements is connected to a first DC power source 12. A discharge lamp 18 is connected to the output terminal of the lighting circuit 100_2 through a choke coil 16. A secondary winding 202_2 of a pulse transformer 202 is connected in parallel with the discharge lamp 18. A primary winding 202_1 of the pulse transformer 202 is connected to the output terminal of a starting circuit 200_2. A second DC power source 66 is connected to the input terminal of the starting circuit 200_2 through a series circuit of a resistor 62 and a transistor 64. In addition, the discharge lamp 18 is connected in parallel with the input terminal of the starting circuit 200_2.

In the starting circuit 200_2, a capacitor 220 is connected in parallel with the second DC power source 66, and a capacitor 224 is connected in parallel with the capacitor 220 through a resistor 222. A constant-voltage conducting element 228 is connected in parallel with the capacitor 224 through a series circuit of the primary winding 202_1 of the pulse transformer 202 and a capacitor 226. Note that diodes 44, 46, 48, and 50 for absorbing surges are connected in parallel with the transistors 36, 38, 40, and 42, respectively.

In the inverter 120, the transistors 36 and 38 are ON/OFF-driven by a low-frequency wave, and the transistors 40 and 42 are ON/OFF-driven by high-frequency wave.

In this modification, a voltage is applied between terminals b_1 and b_2 to turn on the transistor 64, and the starting circuit 200_2 is operated. As a result, a high-voltage pulse is generated from the secondary winding 202_2 of the pulse transformer 202 and is applied to the discharge lamp 18. The discharge lamp 18 is then started to establish an initial glow discharge. After this initial glow discharge is maintained for a certain period of time, a driver (not shown) of the inverter 120 is started. As a result, a switching operation of the transistors 36 and 38 is performed by a low-frequency wave, and a switching operation of the transistors 40 and 42 is performed by a high-frequency wave. With this operation, a lighting wave obtained by superposing a high-frequency wave on a low-frequency wave is supplied from the inverter 120 to the discharge lamp 18, and the initial glow discharge of the discharge lamp 18 is shifted to a main arc discharge.

In this modification, therefore, the same effects as in the above-described embodiments can be obtained.

Furthermore, in this modification, since the lighting wave obtained by superposing the high-frequency wave on the low-frequency wave is supplied from the inverter 120 to the discharge lamp 18 during a normal lighting operation, acoustic resonance can be prevented, and the load characteristics of the lighting circuit can be improved.

Fig. 9 shows still another modification of the starting circuit.

In the circuit shown in Fig. 9, the diodes 44,

46, 48, and 50 which are respectively connected in parallel with the transistors 36, 38, 40, and 42 of the inverter 120 in Fig. 8 are omitted. An inverter 120′ is designed such that transistors 36, 38, 40, and 42 are ON/OFF-driven by a low-frequency wave. That is, the transistors 36 and 40 and the transistors 38 and 42 are alternately operated.

Even in the apparatus wherein the inverter 120′ is driven by a low-frequency wave in this manner, a glow discharge of a discharge lamp 18 is maintained by a starting circuit 200_2 during an initial operation, and the glow discharge of the discharge lamp 18 can be shifted to an arc discharge by subsequently operating a lighting circuit 100_3. Therefore, in this embodiment the same effects as in the above-described embodiments can be obtained.

Fig 10 shows the fourth embodiment of the present invention. In this embodiment, a discharge lamp 18 is maintained in an initial DC arc discharge without establishing a glow discharge, and power required for main lighting of the discharge lamp 18 is subsequently supplied from a lighting circuit 100.

More specifically, a starting circuit 200_3 is connected to the discharge lamp 18. The starting circuit 200_3 includes first and second pulse transformers 230 and 232, a semiconductor switch 234, and a unidirectional three-terminal thyristor 236. The starting circuit 200_3 further includes a first series circuit of a resistor 238, a capacitor 240, and a resistor 242, and a second series circuit of a resistor 244 and a capacitor 246. The discharge lamp 18 is connected to a second DC power source 66 through a series circuit of a transistor 64, a resistor 62, a secondary winding 232_2 of the second pulse transformer, 232 and a secondary winding 230_2 of the first pulse transformer 230.

The above-described first and second series circuits are connected to the second DC power source 66 through a series circuit of the transistor 64 and the resistor 62. One end of a primary winding 230_1 of the first pulse transformer is connected to the node of the resistor 238 and the capacitor 240 of the first series circuit. The other end of the primary winding 230_1 is connected to the negative electrode of the second DC power source 66 through the semiconductor switch 234. One end of the primary winding 232_1 of the second transformer 232 is connected to the node of the resistor 244 and the capacitor 246 of the second series circuit. The other end of the primary winding 232_1 is connected to the negative electrode of the second DC power source 66 through the thyristor 236.

An a_1-a_2 voltage is applied to the base-emitter path of a control transistor 116 of the lighting circuit 100 at a timing shown in Fig. 11A. Similarly, a b_1-b_2 voltage is applied to th base-emitter path of the transistor 64 at a timing shown in Fig. 11B.

In this embodiment, the b_1-b_2 voltage is applied first to the base-emitter path of th transistor 64 at time t_0 so as to turn on the transistor 64. As a result, the starting circuit 200_3 is connected to the second DC power source 66 through the resistor 62, and starts an operation.

In the starting circuit 200_3, the capacitors 240 and 246 are charged, and the semiconductor switch 234 is turned on. After the semiconductor switch 234 is turned on, the capacitor 240 is discharged through the primary winding 230_1 of the first pulse transformer 230 and the semiconductor switch 234. As a result, a high-voltage pulse is generated at the secondary winding 230_2 of the first pulse transformer 230 and is applied to the discharge lamp 18. Subsequently, the thyristor 236 is rendered conductive, and the capacitor 246 is discharged through the primary winding 232_1 of the second pulse transformer 232 and the thyristor 236. With this operation, a high-voltage pulse having energy large enough to start and maintain the initial discharge of the discharge lamp 18 is generated at the secondary winding 232_2 of the second pulse transformer 232, and is supplied to the discharge lamp 18. In this manner, the discharge lamp 18 is maintained in the initial DC arc discharge by the starting circuit 200_3. At this time, the power supplied from the starting circuit 200_3 to the discharge lamp 18 is lower than the predetermined power needed for main lighting.

At time t_1, the a_1-a_2 voltage is applied to the base-emitter path of the transistor 116, and the transistor 116 is turned on. An operation of a driver 104 is started, and transistors 106 and 108 are alternately operated. With this operation, high-frequency power required to maintain the lighting operation is supplied from an inverter 102 to the discharge lamp 18 through a capacitor 14 and a choke coil 16.

Subsequently, the transistor 64 is turned off at time t_2 to stop the starting circuit 200_3.

In this manner, the discharge lamp 18 is set in a lighting state after the arc discharge is directly maintained without a glow discharge.

This system, therefore, can prevent a lighting failure which is often caused when a glow discharge is shifted to an arc discharge. The lamp voltage of a discharge lamp is high during a glow discharge. Therefore, in order to connect the discharge lamp to a lighting circuit in a glow discharge state, the withstand voltage of a switching element of the lighting circuit must be set to be high. In this embodiment, however, since the discharge voltage is connected to the lighting circuit in an arc discharge state, the switching el ment of the lighting circuit need not have a high withstand voltage. In other words, a breakdown of the switch-

ing element of the lighting circuit can be further r liably pr vented.

Note that the arrang ment of the starting circuit is not limited to the one described in this embodiment. For example, the starting circuit may have arrangements shown in Figs. 12 and 13.

Fig. 12 shows a circuit arrangement of a modification of the starting circuit of the discharge lamp lighting apparatus in Fig. 10. Referring to Fig. 12, a starting circuit 200_4 includes a pulse transformer 248 as a high voltage generator constituted by a primary winding 248_1 and a secondary winding 248_2. In the starting circuit 200_4, one end of the primary winding 248_1 of the pulse transformer 248 is connected to the node of a resistor 250 and a capacitor 252. The other end of the primary winding 248_1 is connected to the other end of a discharge lamp 18 through a semiconductor switch 254. In addition, one end of the discharge lamp 18 is connected to the other end of the resistor 250 through the secondary winding 248_2 of the pulse transformer 248. The other end of the discharge lamp 18 is connected to the other end of the capacitor 252.

Fig. 13 shows a circuit arrangement of another modification of the starting circuit of the discharge lamp lighting apparatus shown in Fig. 10. Referring to Fig. 13, a starting circuit 200_5 includes a pulse transformer 254 as a high voltage generator constituted by two primary windings 254_{11} and 254_{12} and one secondary winding 254_2. One end of one primary winding 254_{11} of the pulse transformer 254 is connected to the node of a resistor 256 and a semiconductor switch 258. The other end of the primary winding 254_{11} is connected to the other end of a discharge lamp 18 through a series circuit of a capacitor 260 and a resistor 262. In the starting circuit 200_5, one end of the other primary winding 254_{12} is connected to the node of a resistor 264 and a capacitor 266, and the other end thereof is connected to the other end of the discharge lamp 18 through a unidirectional three-terminal thyristor 268. In addition, one end of the discharge lamp 18 is connected to the other end of each of the resistors 256 and 264 through the secondary winding 254_2 of the pulse transformer 254. The other end of the discharge lamp 18 is connected to the other end of each of the semiconductor switch 258 and the capacitor 266. In addition, the gate of the thyristor 268 is connected to the node of the capacitor 260 and the resistor 262.

If the starting circuit shown in Fig. 10, 12, or 13 is used, a circuit for directly causing an arc discharge of a discharge lamp can be applied t the lighting circuit shown in Fig. 3.

Fig. 14 shows a circuit arrangement of the fifth embodiment of the present invention.

Referring to Fig. 14, a discharge lamp lighting apparatus is designed such that a boosting inverter 130 is a DC power source 12. The inverter 130 is constituted by a known circuit. Mor specifically, the inverter 130 is constituted by a pair of MOS transistors 106 and 108, a push-pull control circuit 132 for controlling a switching operation of the transistors 106 and 108, and an output transformer 134.

A known voltage doubler rectifier 144 constituted by diodes 136 and 138 and capacitors 140 and 142 is connected to the output terminal of the inverter 130, i.e., a secondary winding 134_2 of the output transformer 134. A half-bridge circuit 146 constituting a lighting circuit 100_4 is connected between the two ends of a series circuit of the capacitors 140 and 142 as the output terminals of the voltage doubler rectifier 144.

The half-bridge circuit 146 includes a pair of known MOS transistors 148 and 150 which are connected in series, and a half-bridge drive controller 152 for controlling a switching operation of the transistors 148 and 150. In addition, the drain of the transistor 148 is connected to the positive terminal of the capacitor 140, and the source of the transistor 150 is connected to the negative terminal of the capacitor 142. A discharge lamp 18 is connected between the node of the source of the transistor 148 and the drain of the transistor 150, and the node of the capacitors 140 and 142 through a series circuit of a first energization detector 154, a normally-closed contact 156m of a third relay 156, and a current limiting choke 158.

A starting circuit 200_6 is connected to the discharge lamp 18 through a second energization detector 160. The starting circuit 200_6 is connected to the capacitor 140 through a normally-open contact 162m of a fourth relay 162 so as to obtain an operating power source from the capacitor 140. A capacitor incorporated in the starting circuit 200_6 is charged in accordance with a predetermined time constant. When the charge level of the capacitor reaches a predetermined level, the capacitor is discharged, and a current including a pulse is generated by a pulse transformer as a high-voltage generator. This operation is intermittently repeated.

A relay switching circuit 164 is connected to the DC power source 12.

For example, the relay switching circuit 164 has an arrangement shown in Fig. 15. More specifically, a series voltage divider constituted by resistors 302 and 304, a series circuit of an npn transistor 306 and the fourth relay 162, and a series circuit of an npn transistor 308 and the third relay 156 are connected to the DC power source 12. Note that diodes 310 and 312 for absorbing surges are connected in parallel with the relays 156 and 162, respectively.

The noninverting input terminal (+) of a com-

parator 314 is connected to the node of the resistors 302 and 304. A resistor 316 is connected betwe n th output terminal and the noninv rting input terminal (+) f the comparator 314. The inverting input terminal (-) of the comparator 314 is connected to the positive electrode of the power source 12 through a series circuit of a diode 318, a resistor 320, and a phototransistor 322T of a photocoupler 322, which constitute the second energization detector 160. A light-emitting diode 322D of the photocoupler 322 is inserted in the energization path between the starting circuit 2006 and the discharge lamp 18.

The first energization detector 154 includes a current transformer 324. A primary winding 324_1 of the transformer 324 is inserted in the energization path between the half-bridge circuit 146 and the discharge lamp 18.

A resistor 326 is connected between the two ends of a secondary winding 324_2 of the current transformer 324. The two ends of the secondary winding 324_2 are respectively connected to one end of a capacitor 334 through diodes 328 and 330 and a resistor 332. In addition, an intermediate tap of the secondary winding 324_2 is connected to the other end of the capacitor 334 and to the negative electrode of the DC power source 12. The node of the capacitor 334 and the resistor 332 is connected to the inverting input terminal (-) of the comparator 314 through a diode 336.

A series circuit of resistors 338 and 340 and a series circuit of a diode 342 and a capacitor 344 are connected between the output terminal of the comparator 314 and the negative electrode of the DC power source 12. The capacitor 334 constitutes a delay circuit together with a series circuit of resistors 346 and 348, which is connected in parallel therewith. In addition, the base of the transistor 308 is connected to the node of the resistors 338 and 340. Similarly, the base of the transistor 306 is connected to the node of the resistors 346 and 348 through a Zener diode 350.

An operation of this embodiment having such an arrangement will be described below with reference to Figs. 16A through 16I and Figs. 17A through 17I.

When the DC power source 12 is turned on at time t_{11} as shown in Fig. 16A, an output from the comparator 314 is set at high level as shown in Fig. 16B. The transistors 306 and 308 are then turned on, as shown in Figs. 16C and 16F. As shown in Figs. 16D and 16G, the fourth and third relays 162 and 156 are operated with a slight delay at tim t_{12}. As a result, the normally-op n contact 162m of the fourth r lay 162 is closed, and the normally-closed contact 156m of the third relay 156 is opened.

In this mann r, the starting circuit 200_6 is connected to the power source 12, and starts an operation. In the starting circuit 200_6, when charging of th capacitor is started, and the charge level reaches a predetermined level a predetermined period of time T_1 (time t_{13}) after time t_{12}, a pulse shown in Fig. 16E is generated and supplied to the discharge lamp 18. When the discharge lamp 18 starts initial discharge, a discharge current flows upon reception of the pulse. At this time, the power supplied from the starting circuit 200_6 is lower than the power needed for main lighting.

When this current flows, the light-emitting diode 322D of the photocoupler 322 is operated, and the phototransistor 322T is turned on. As a result, a high-level voltage is applied to the inverting input terminal (-) of the comparator 314 through the diode 318. The input level of the inverting input terminal (-) then becomes higher than that of the noninverting input terminal (+), and the output level of the comparator 314 goes to low level. Subsequently, as shown in Fig. 16F, the transistor 308 is immediately turned off at time t_{13}, and the third relay 156 is turned off with a slight delay at time t_{14}. As a result, the normally-closed contact 156m of the relay 156 is turned on.

In this manner, as shown in Fig. 16H, a power required for main discharge starts to be supplied from the half-bridge circuit 146 to the discharge lamp 18. When this current supply is started, a voltage is generated at the secondary winding 324_2 of the current transformer 324, and application of a high-level voltage to the inverting input terminal (-) of the comparator 314 is started also through the diode 336.

When an output from the comparator 314 is set at low level, the capacitor 344 is discharged through the resistors 346 and 348. The transistor 306 is then turned off after a lapse of a time T_2 ($< T_1$) (at time t_{15}) before the next pulse is generated by the starting circuit 200_6 as shown in Fig. 16C, and the fourth relay 162 is turned off with a slight delay at time t_{16} as shown in Fig. 16D.

In this manner, the starting circuit 200_6 is disconnected from the power source 12, and the current supplying operation to the discharge lamp 18 is stopped. After time t_{16}, a current is supplied only from the half-bridge 146, and the lighting state of the discharge lamp 18 is maintained. As a result, a lamp discharge current shown in Fig. 16I flows in the discharge lamp 18 after the operation is started.

The above-described operation is based on the assumption that the discharge lamp 18 is normally started. However, the discharge lamp 18 may not b smoothly restarted. For example, the discharg lamp 18 may not be started in response to an initial puls , or a lighting failure may be caused after the discharg lamp 18 is lighted. Figs. 17A through 17I

are timing charts for xplaining such a case.

Assum that the DC power source 12 is turned off at time t_{21} and is subsequently turned on again at time t_{22} as shown in Fig. 17A. In this case, as shown in Figs. 17C and 17F, the transistors 306 and 308 are turned on. As shown in Figs. 17D and 17G, the fourth and third relays 162 and 156 are then operated at time t_{23}. As a result, the normally-open contact 162m of the fourth relay 162 is closed, and the normally-closed contact 156m of the third relay 156 is opened.

Assume in this case that an initial pulse is supplied from the starting circuit 200_6 to the discharge lamp 18 at time t_{24} as shown in Fig. 17E, but the discharge lamp 18 is not started. In the starting circuit 200_6, charging of the capacitor is started again, and a second pulse is generated after a lapse of a predetermined time T_3 (at time t_{25}). As a result, the discharge lamp 18 is started, and the transistor 308 is turned off, as shown in Fig. 17F. The third relay 156 is then turned off at time t_{26}, as shown in Fig. 17G. With this operation, the half-bridge circuit 146 is connected to the discharge lamp 18, and a current is supplied from the circuit 146 to the discharge lamp 18, as shown in Fig. 17H.

Subsequently, as shown in Fig. 17C, the transistor 306 is turned off with a delay of a predetermined period of time T_4, i.e., at time t_{27}. The fourth relay 162 is turned off (at time t_{28}), as shown in Fig. 17D. As a result, the current supplying operation from the starting circuit 200_6 to the discharge lamp 18 is stopped.

If a lighting failure of the discharge lamp 18 occurs in this state at time t_{29} as shown in Fig. 17I, no voltage is generated at the secondary winding 324_2 of the current transformer 324. The phototransistor 322T of the photocoupler 322 has already been turned off upon operation stop of the starting circuit 200_6. Therefore, the input level of the inverting input terminal (-) of the comparator 314 goes to low level. As a result, the output from the comparator 314 is inverted from low level to high level, as shown in Fig. 17B.

In response to this level change, the transistor 306 is turned on at time t_{30} to operate the fourth relay 162, and the normally-open contact 162m is closed to immediately operate the starting circuit 200_6. Meanwhile, the transistor 308 is turned on to operate the third relay 156, and the normally-closed contact 156m is opened to immediately disconnect the half-bridge circuit 146 from the discharge lamp 18.

As described above, when a lighting failure of the discharge lamp 18 occurs, th starting circuit 200_6 is immediately operated, and the half-bridg circuit 146 is immediately disconnected from the discharge lamp 18, thus controlling starting/lighting of th discharge lamp 18.

When the starting circuit 200_6 is operated to supply a current including a pulse to the discharg lamp 18, since the half-bridge 146 equivalent t the lighting circuit 100_4 is disconnected from the discharge lamp 18, there is no possibility that the pulse enters the half-bridge circuit 146 and damages semiconductor elements in the circuit 146, e.g., the MOS transistors 106 and 108.

In addition, while a current is supplied from the starting circuit 200_6 to the discharge lamp 18, the half-bridge circuit 146 is connected to the discharge lamp 18 so as to start supply of a current from the half-bridge circuit 146 to the discharge lamp 18. Thereafter, the operation of the starting circuit 200_6 is stopped by disconnecting the circuit 200_6 from the power source before the next pulse is generated by the circuit 200_6. Therefore, the power supplying operations from the starting circuit 200_6 and the half-bridge circuit 146 overlap, and the lighting operation of the discharge lamp 18 can be stably maintained. Furthermore, even if the current supplying operations overlap, since no pulse is generated by the starting circuit 200_6 during this period, there is no possibility that a pulse runs around and enters the half-bridge circuit 146.

In this embodiment, the energization detectors are constituted by a photocoupler, a current transformer, and the like. However, the present invention is not limited to this.

Furthermore, in this embodiment, supply of a current from the starting circuit to the discharge lamp is stopped by disconnecting the starting circuit from the power source. However, this operation may be performed by disconnecting the starting circuit from the discharge lamp.

Moreover, in this embodiment, the lighting circuit is constituted by the half-bridge circuit. However, the present invention is not limited to this.

Claims

1. A method of lighting a discharge lamp, comprising the steps of supplying a starting high voltage, required for starting a discharge of the discharge lamp, from a starting circuit to the discharge lamp; causing the initial discharge by supplying power lower than a predetermined power from the starting circuit, after the discharge of the discharge lamp is started; and supplying a predetermined power required for main lighting of the discharge lamp from a lighting circuit to the discharge lamp, after the initial discharge is started,
characterized by further comprising the step of maintaining the initial discharg by supplying power lower than a predetermined power from the starting circuit (200), after th discharge of the

discharg lamp (18) is started

2. A method according to claim 1, characterized in that said initial discharge is an arc discharge.

3. A method according to claim 1, characterized in that said initial discharge is a glow discharge.

4. A method according to claim 3, characterized in that the step of supplying the predetermined power required for main lighting includes the step of shifting the initial glow discharge to an arc discharge.

5. A method according to claim 2, characterized in that said initial discharge is a DC arc discharge.

6. A discharge lamp lighting apparatus comprising a discharge lamp; a lighting circuit, having an output terminal connected to said discharge lamp, for main lighting said discharge lamp with a predetermined electric power; and a starting circuit, connected to said discharge lamp in parallel with said lighting circuit, for applying a pulse voltage to said discharge lamp to start discharge, and causing the initial discharge with a power lower than a predetermined value after the start of the discharge, characterized in that

said starting circuit (200) maintains the initial discharge with power lower than a predetermined value, after the discharge of discharge lamp (18) is started, and

that there is further provided a control circuit (64, 104, 116) for controlling a timing at which the output from said lighting circuit (100) is supplied to said discharge lamp (18) after said discharge lamp starts to operate and while the initial discharge is maintained.

7. An apparatus according to claim 6, characterized in that said control circuit (64, 104, 116) controls a drive starting timing of said lighting circuit (100).

8. An apparatus according to claim 6, characterized by further comprising switching means (22), connected between said discharge lamp (18) and said lighting circuit (100), for turning on/off the output from said lighting circuit (100) to said discharge lamp (18), said control circuit (64, 104, 116) controlling an ON/OFF timing of said switching means (22).

9. An apparatus according to claim 6, characterized by further comprising an impedance element (16) connected in series with said starting circuit (200) and said discharge lamp (18).

10. An apparatus according to claim 6, characterized by further comprising means for turning off said starting circuit (200) after the output from said lighting circuit (100) is supplied to said discharge lamp (18).

11. An apparatus according to claim 8, characterized by further comprising first energization detecting means (154) for detecting an energization state between said starting circuit (200) and said discharge lamp (18), second energization detecting means (160) for detecting an energization state between said lighting circuit (200) and said discharge lamp (18), said control means (164) starting a power supplying operation from said starting circuit (200) to said discharge lamp (18) and turning off said switching means (22) upon turning on of said power source, keeping said switching means ON when said first energization detecting means (154) detects an energization state, and stopping the power supplying operation from said starting circuit (200) to said discharge lamp (18) with a delay time shorter than a period of time after which a next pulse is generated by said starting circuit (200) when said second energization detecting means (160) detects an energization state and maintains the energization state.

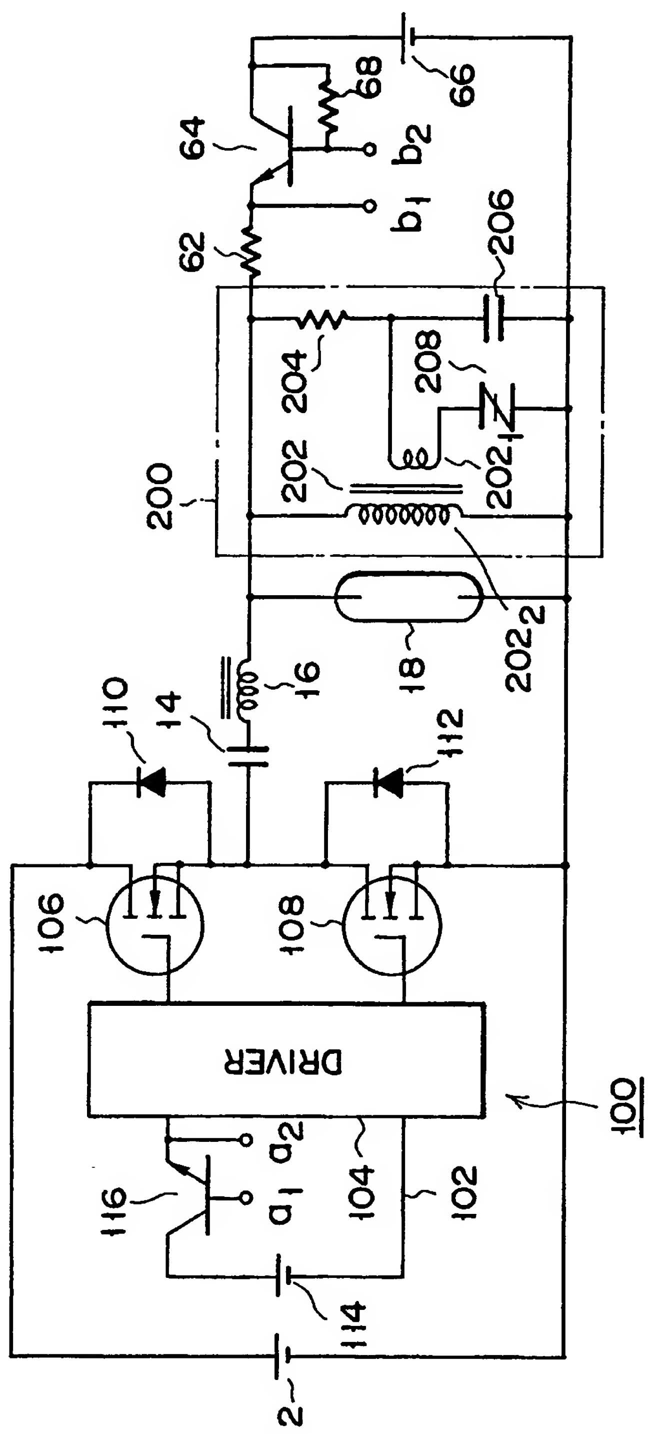

DRIVER
100
102
104
106
108
110
112
114
116
12
14
16
18
200
202
202₁
202₂
204
206
208
62
64
66
68
a₁
a₂
b₁
b₂

FIG. 1

FIG. 2A

FIG. 2B

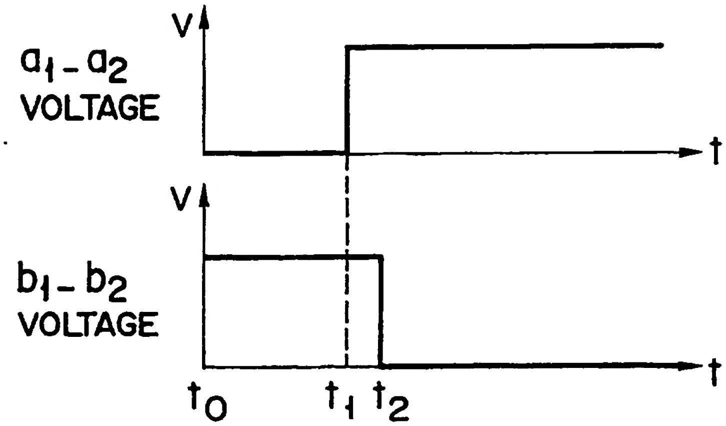


FIG. 4A

FIG. 4B

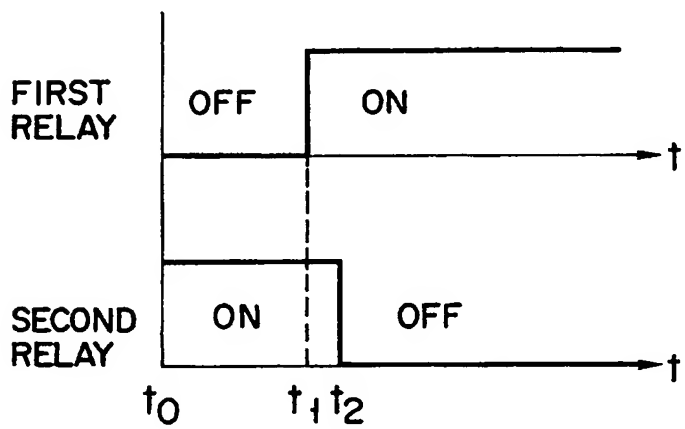
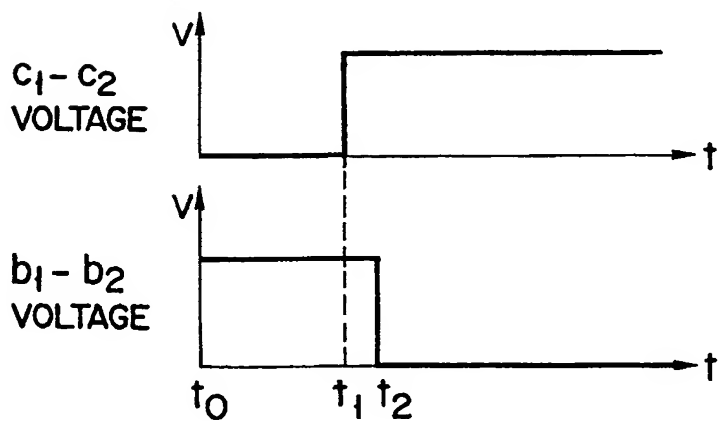


FIG. 6A

FIG. 6B



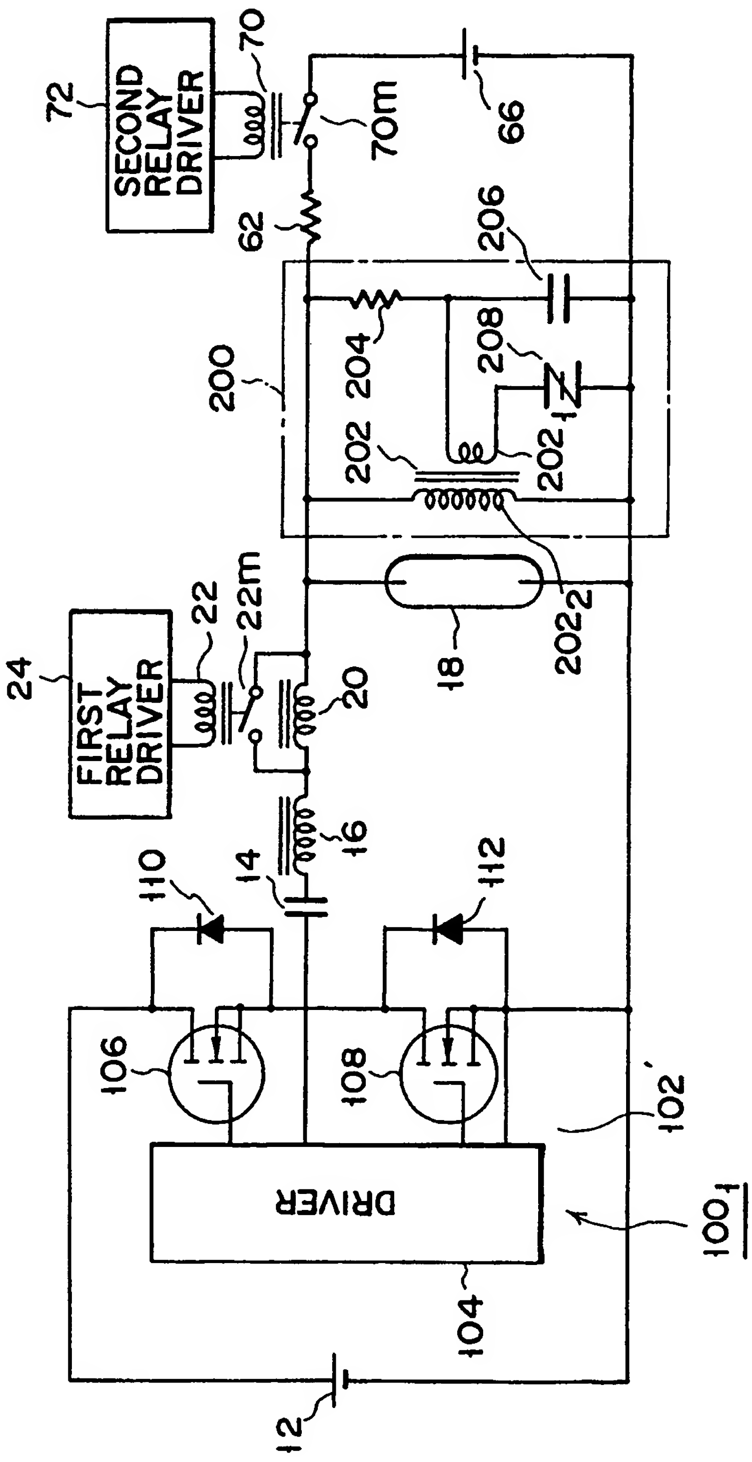

SECOND RELAY DRIVER
FIRST RELAY DRIVER
DRIVER
72
70
70m
66
62
206
200
204
208
202
202_1
202_2
24
22
22m
20
18
16
14
110
112
106
108
102
104
100_1
12

FIG. 3

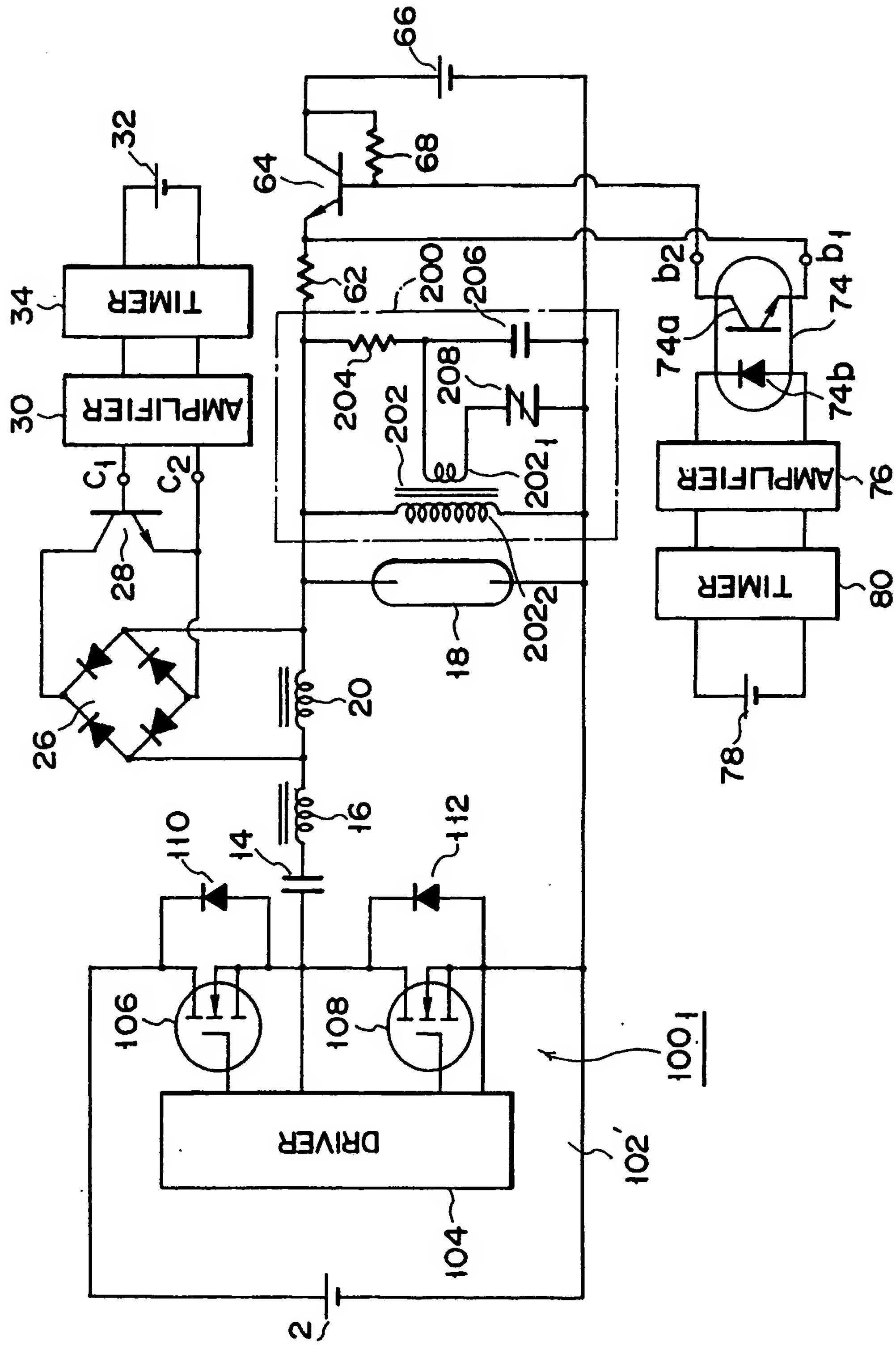

TIMER
AMPLIFIER
TIMER
AMPLIFIER
DRIVER
12
14
16
18
20
26
28
30
32
34
62
64
66
68
74
74a
74b
76
78
80
100_1
$102'$
104
106
108
110
112
200
202
202_1
202_2
204
206
208
C_1
C_2
b_1
b_2

FIG. 5

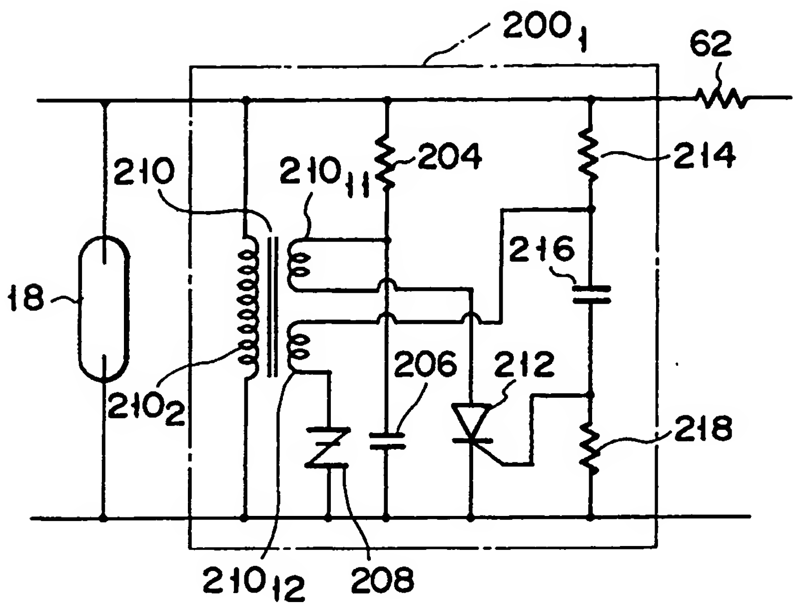

200₁
62
210
210₁₁
204
214
18
216
206
212
210₂
218
210₁₂
208

FIG. 7

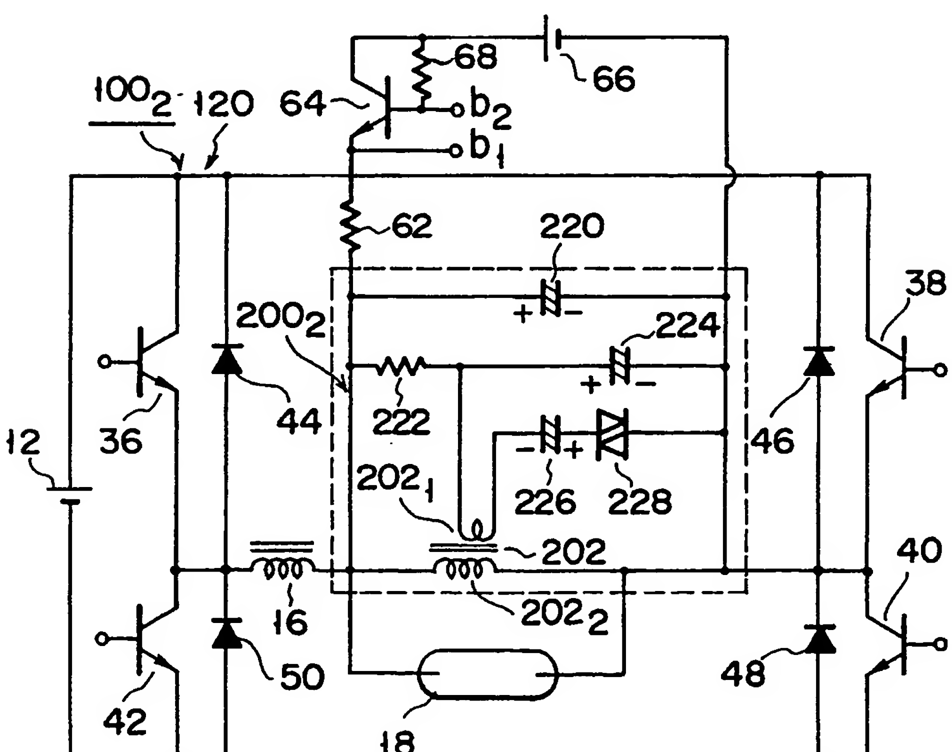
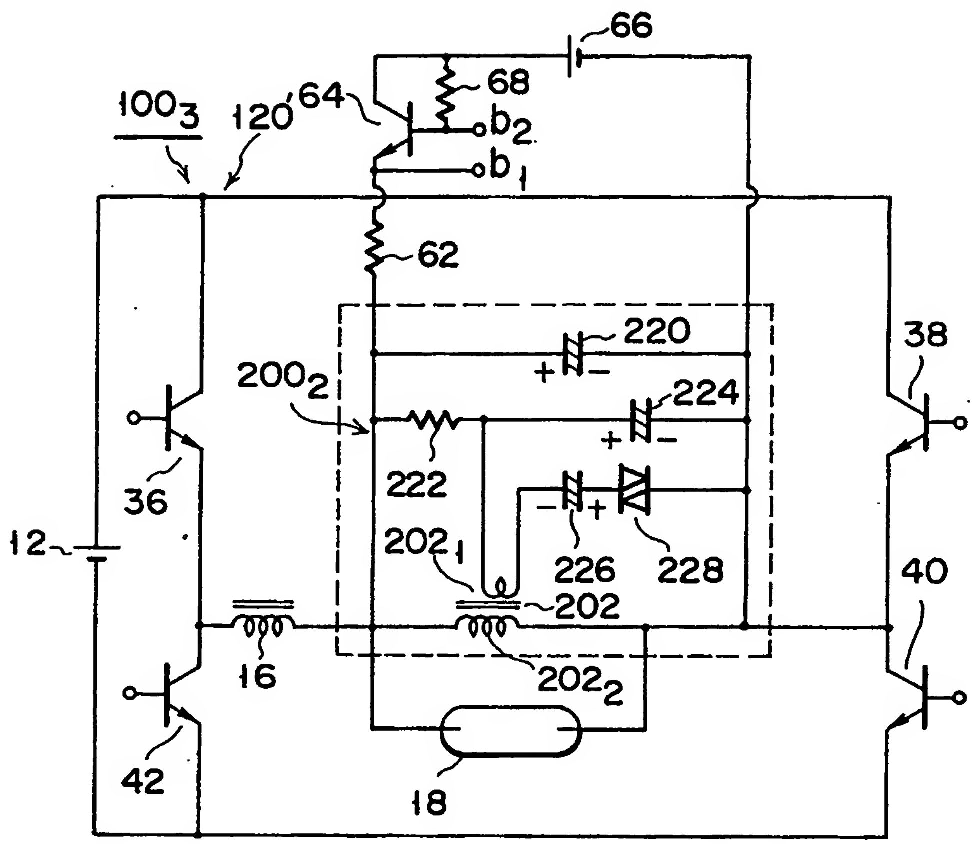

68
66
100₂
120
64
b₂
b₁
62
220
38
200₂
224
222
44
46
12
36
226
228
202₁
202
40
16
202₂
50
48
42
18

FIG. 8


66
68
100_3
120
64
b_2
b_1
62
220
38
200_2
224
222
36
12
202_1
226
228
40
202
16
202_2
42
18

F I G. 9

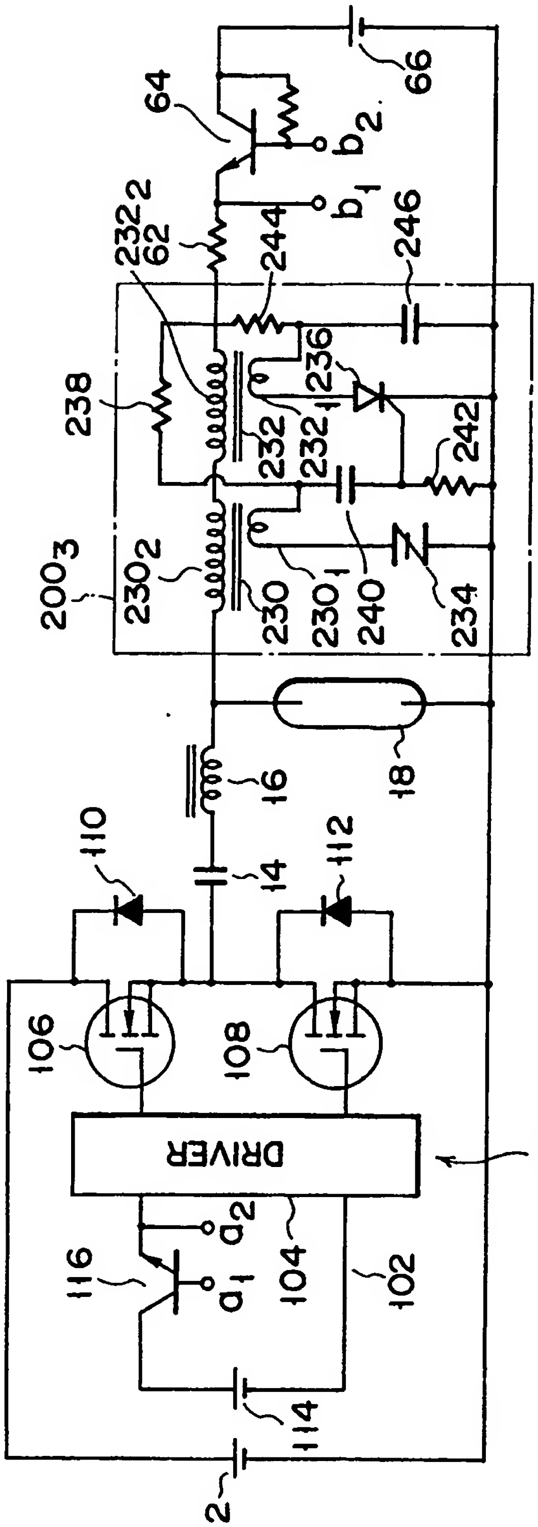


FIG. 10

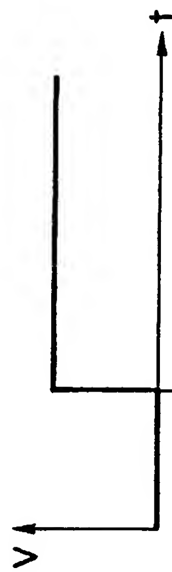


FIG. 11A $a_1 - a_2$ VOLTAGE

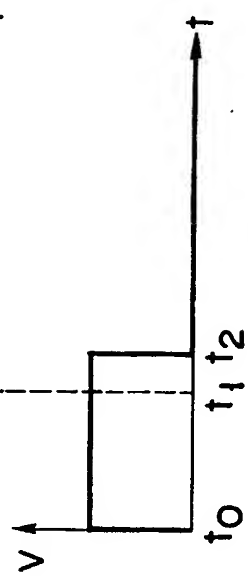
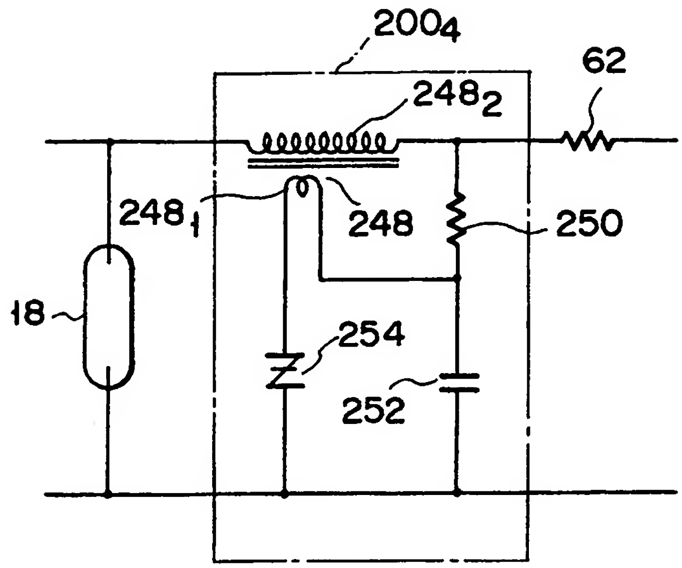
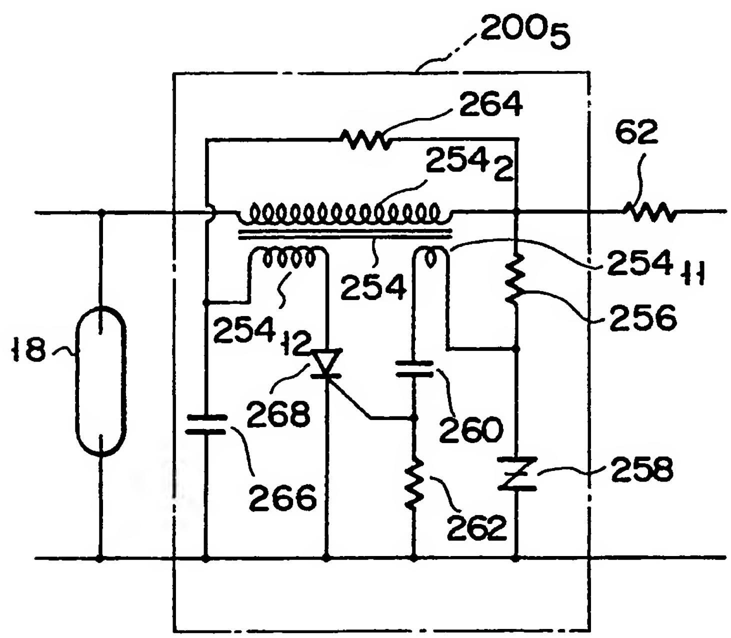


FIG. 11B $b_1 - b_2$ VOLTAGE


200₄
62
248₂
248₁
248
250
18
254
252

F I G. 12


200₅
264
62
254₂
254₁₁
254
256
254₁₂
18
268
260
258
266
262

F I G. 13

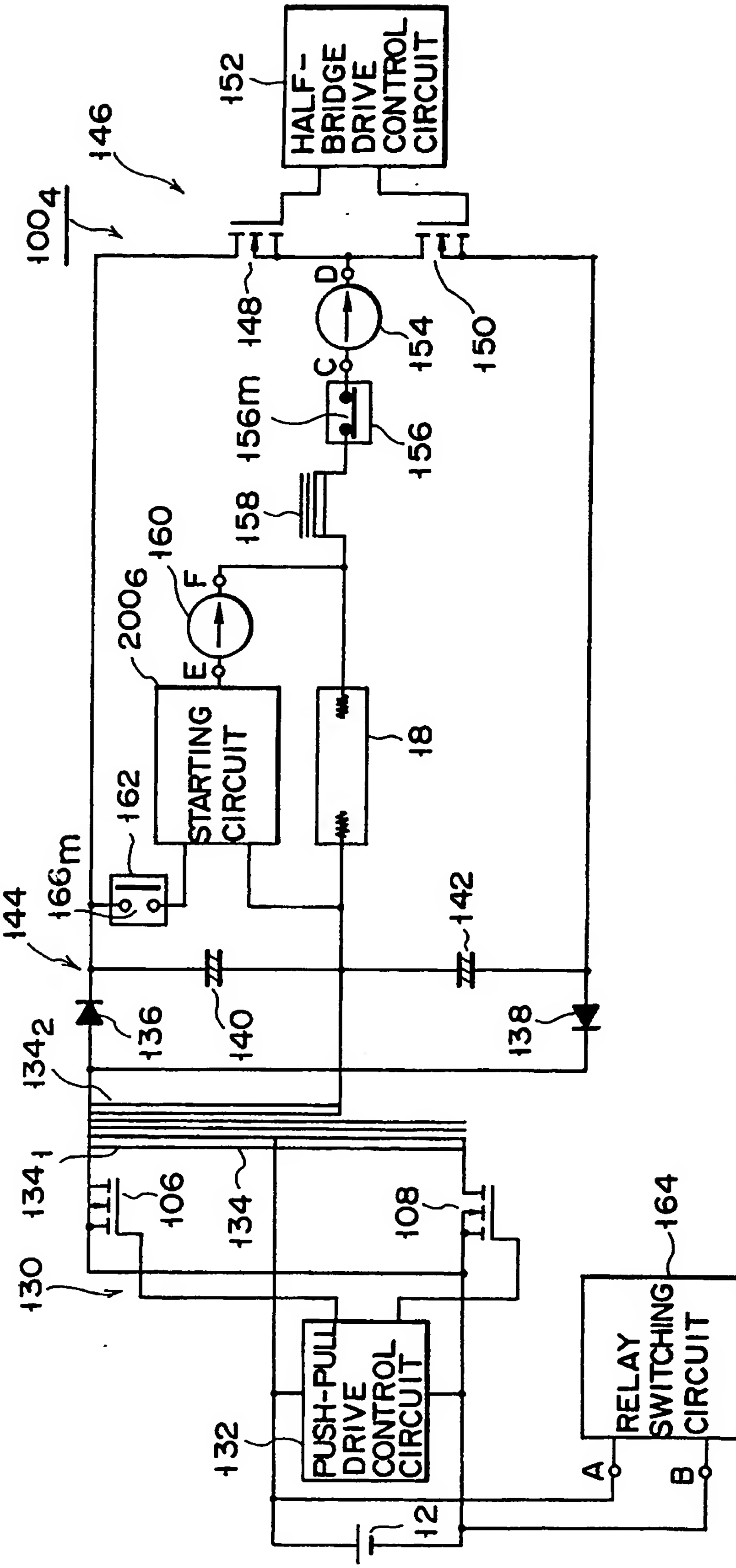

HALF-BRIDGE DRIVE CONTROL CIRCUIT
152
146
100_4
148
150
154
C
D
156m
156
158
160
E
F
2006
STARTING CIRCUIT
162
166m
18
144
136
140
142
138
134_2
134_1
134
106
108
130
PUSH-PULL DRIVE CONTROL CIRCUIT
132
12
A
B
RELAY SWITCHING CIRCUIT
164

FIG. 14

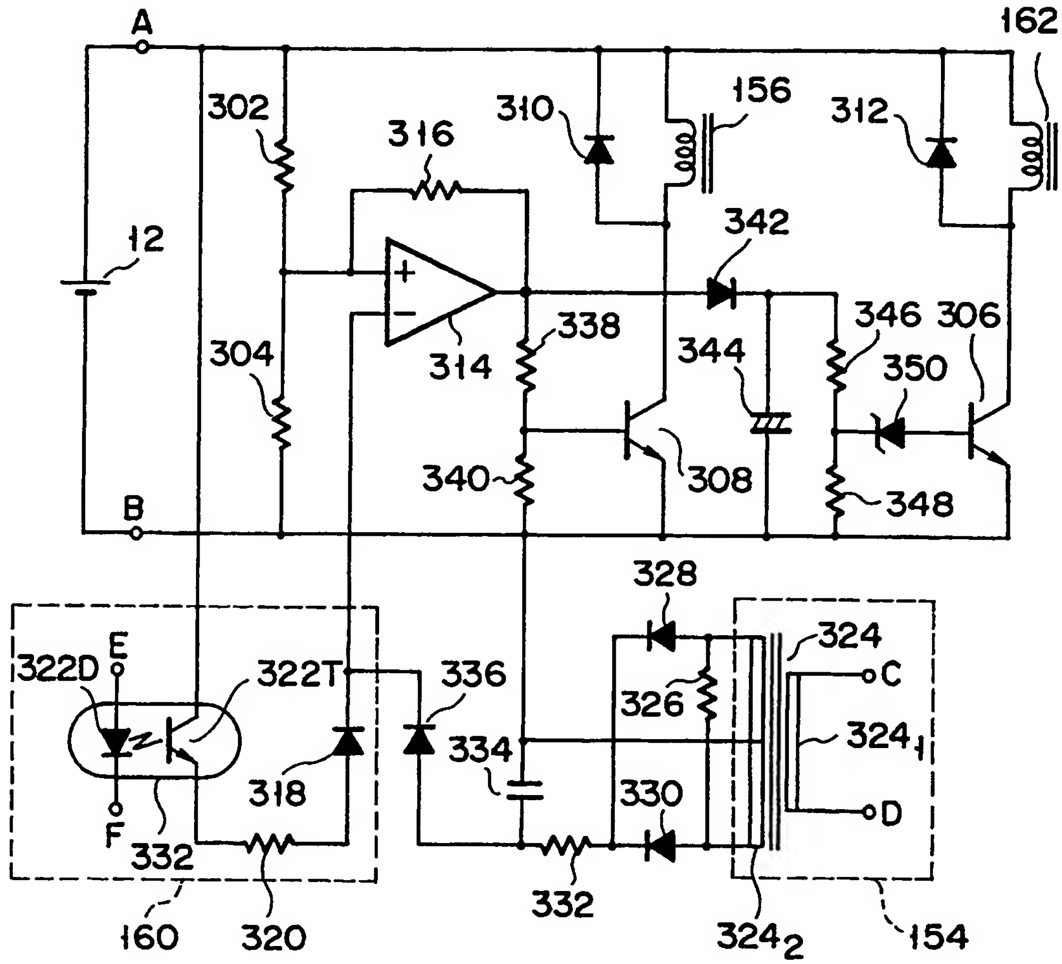

A
162
302
316
310
156
312
12
342
304
314
338
344
346
306
350
340
308
348
B
328
324
E
322D
322T
336
C
326
334
324_1
318
330
F
332
D
332
160
320
332
324_2
154

FIG. 15

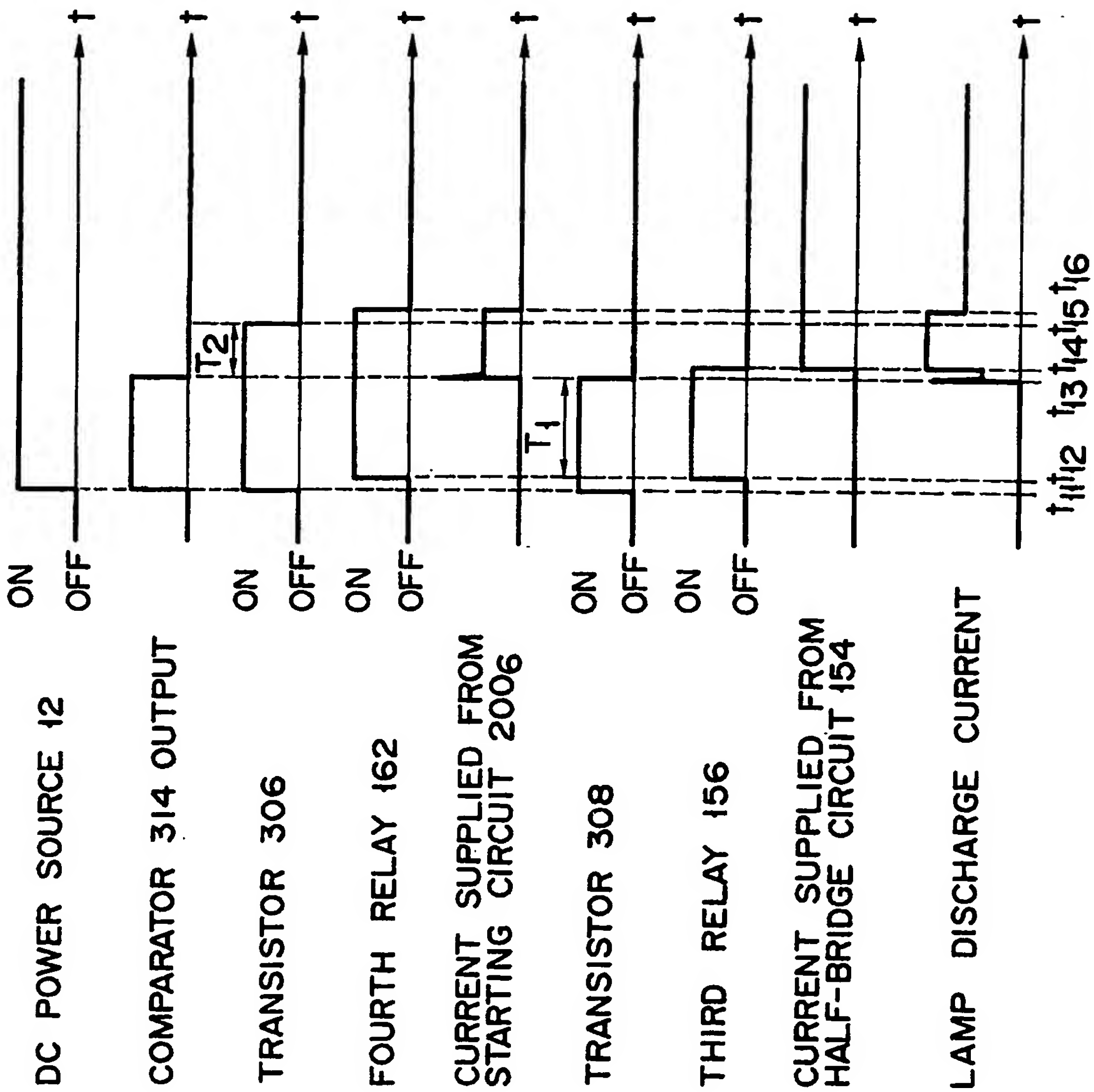


FIG. 16A
FIG. 16B
FIG. 16C
FIG. 16D
FIG. 16E
FIG. 16F
FIG. 16G
FIG. 16H
FIG. 16I

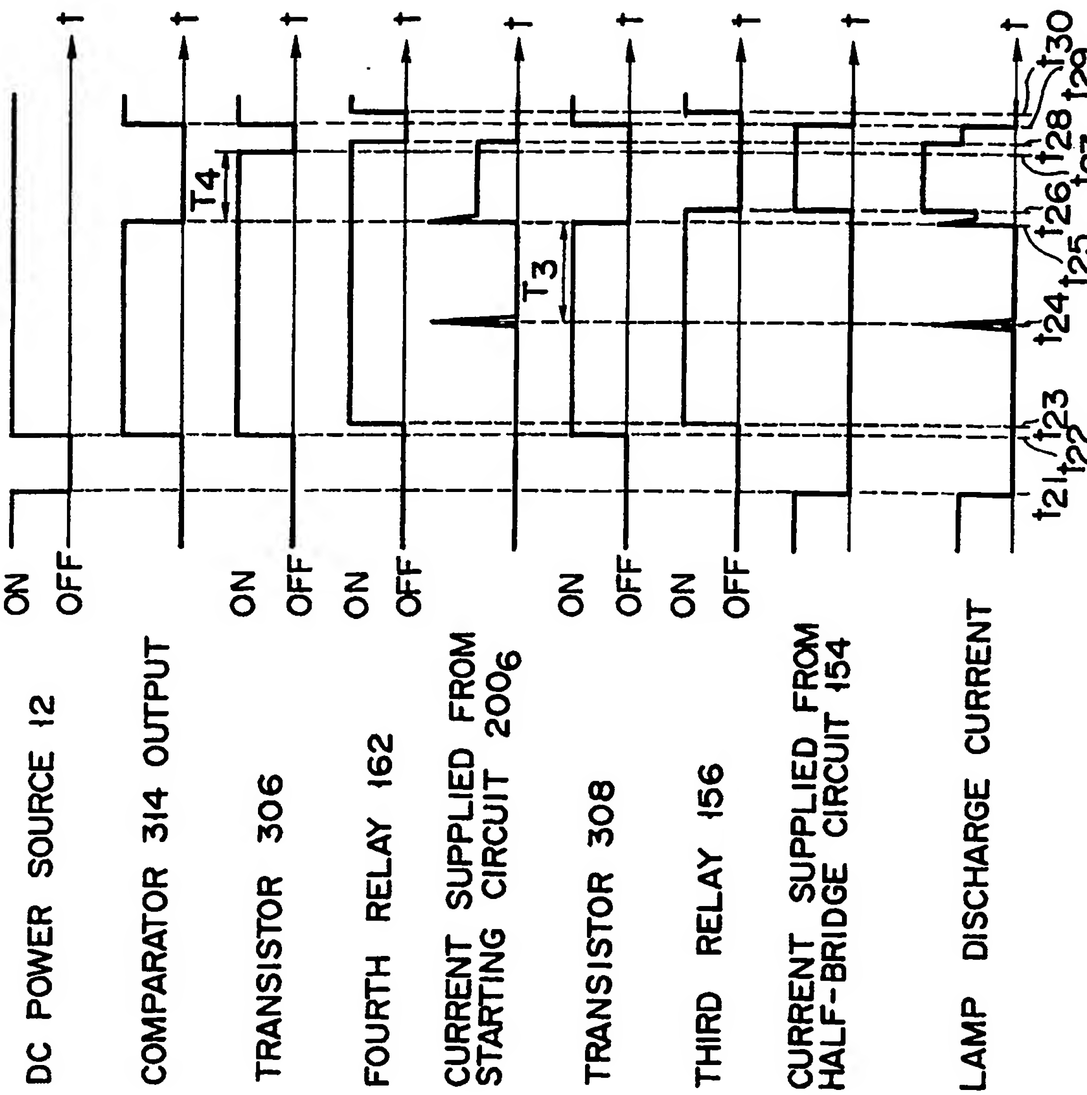


FIG. 17A

FIG. 17B

FIG. 17C

FIG. 17D

FIG. 17E

FIG. 17F

FIG. 17G

FIG. 17H

FIG. 17I